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Earth Clouds, Aerosols and Radiation Explorer

The role of clouds and aerosols in radiation and in hydrological processes

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on behalf of the EarthCARE Joint Mission Advisory Group

Summary

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1) *Why* do we need *EarthCARE ?* – scientific data needs

2) *How* do we satisfy these needs with *EarthCARE ?*

3) Some specifics on the passive instruments, especially the *BBR*

4) *Conclusion*

The Challenge

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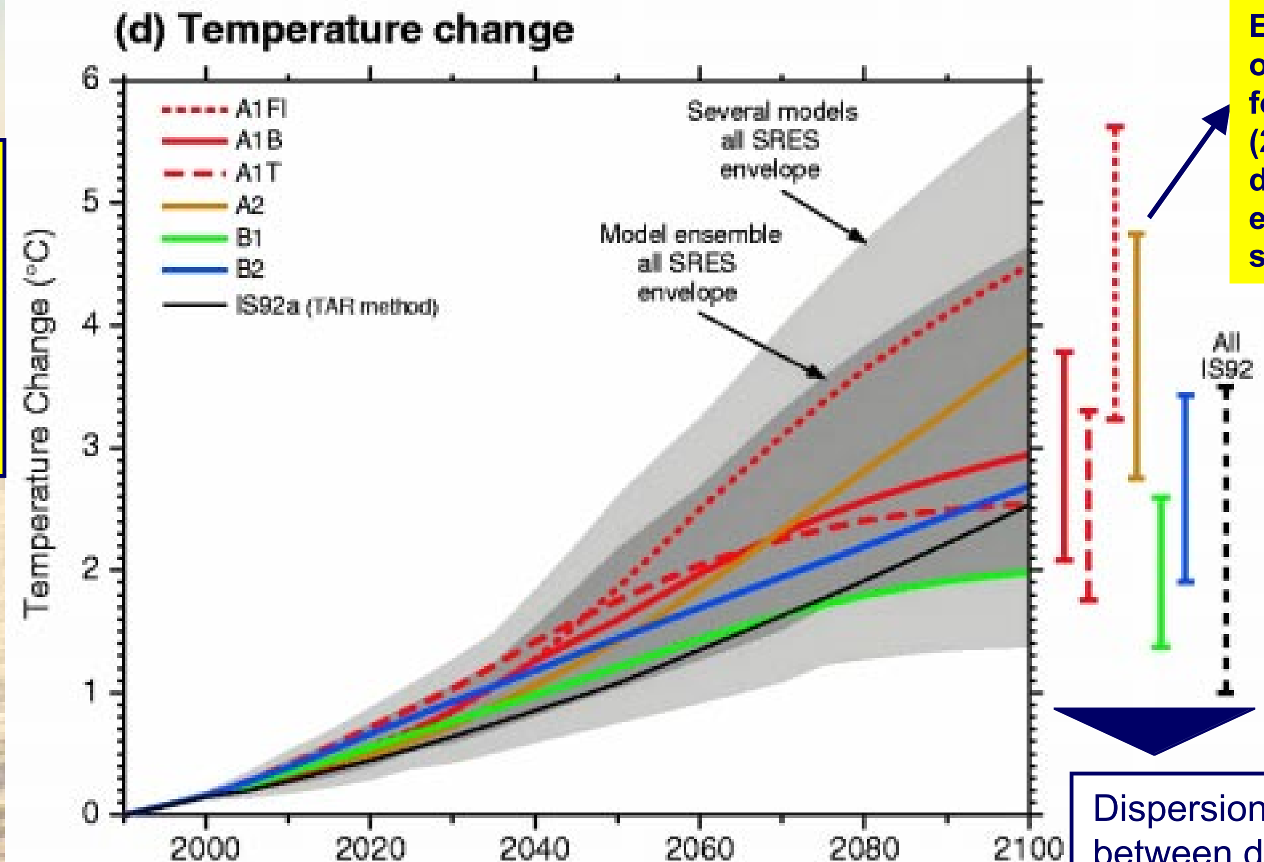
Forecasts of global warming for the 21st century

Forecasts:
climate models using different expected politico-economic social & industrial development scenarios

different **emission scenarios (SRES)**



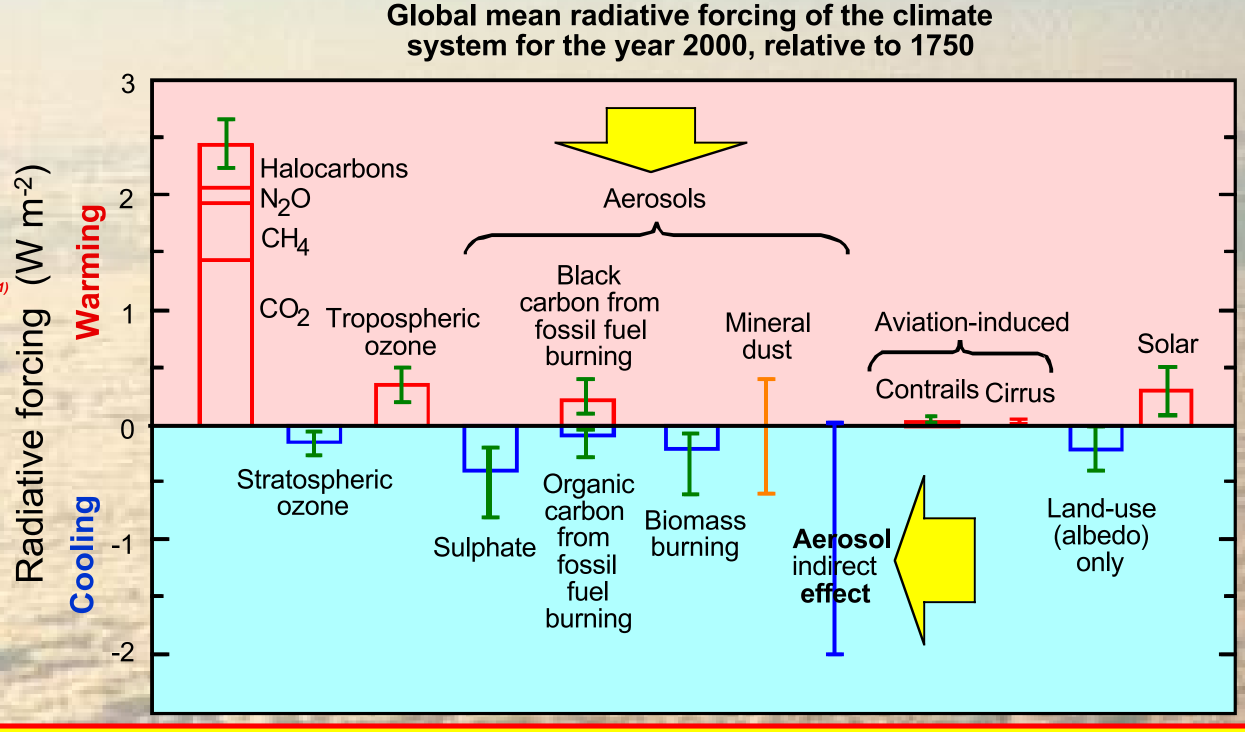
IPCC TAR 2001

Each bar is one model forecast (2100), different emission scenarios

Dispersion between different models (bars) shows ***model*** uncertainties

Importance, uncertainties and understanding of EXTERNAL FACTORS forcing climate change

The challenge
Radiative forcing (IPCC 2001)



Large uncertainties for aerosol effects – especially indirect effect whereby aerosols change cloud properties

The Cloud Feedback Challenge

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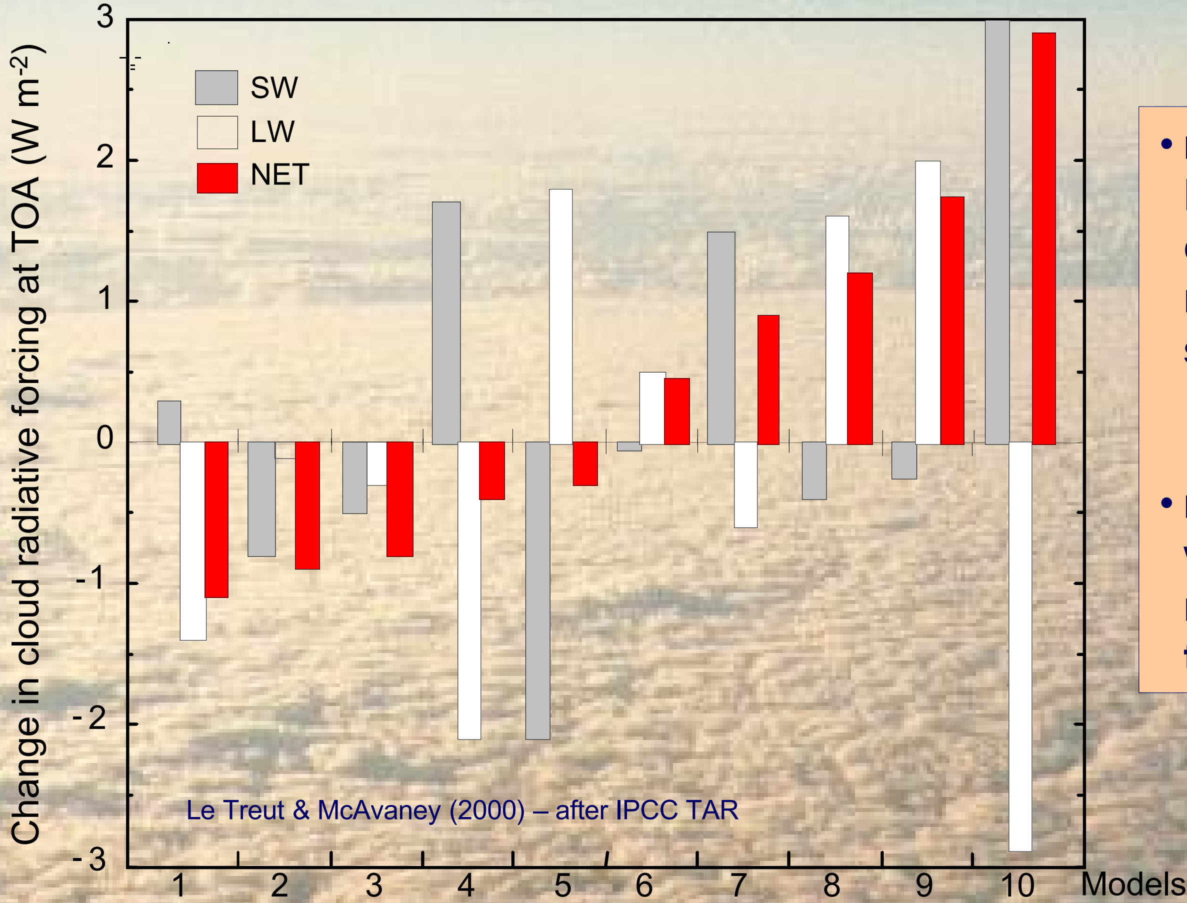
Change in TOA fluxes in 10 models due to clouds for CO_2 doubling

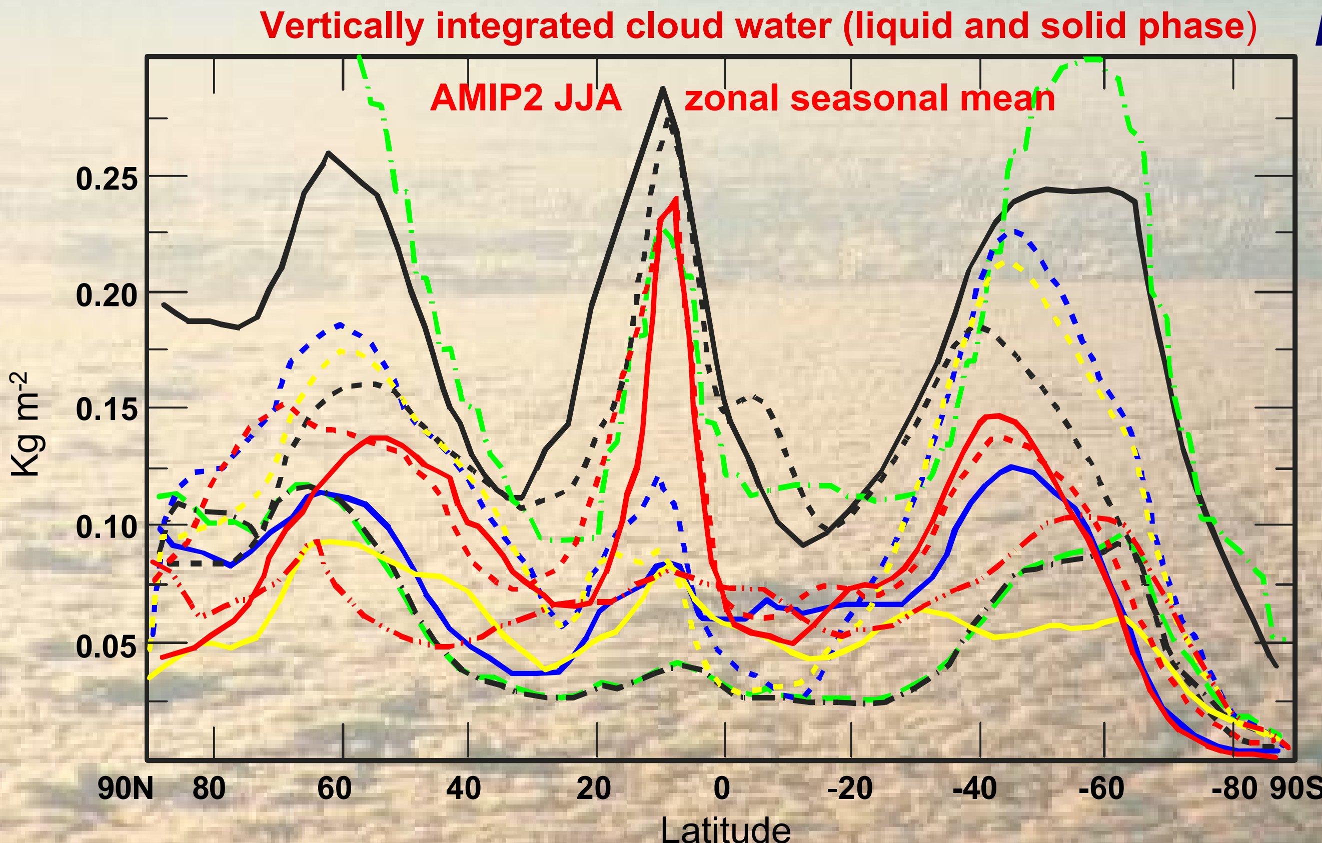


- more aerosol and low cloud cool the climate by reflecting more sunlight to space
- more high clouds warm the climate by reducing the IR loss to space

dispersion of the predictions α similar to IPCC external factors

Atmospheric Models Intercomparison Project – 14 Climate Models

Present Climate



But all models are tuned to give the same mean TOA radiative flux

Cloud parameterisation deficient α can't model clouds consistently in the present climate

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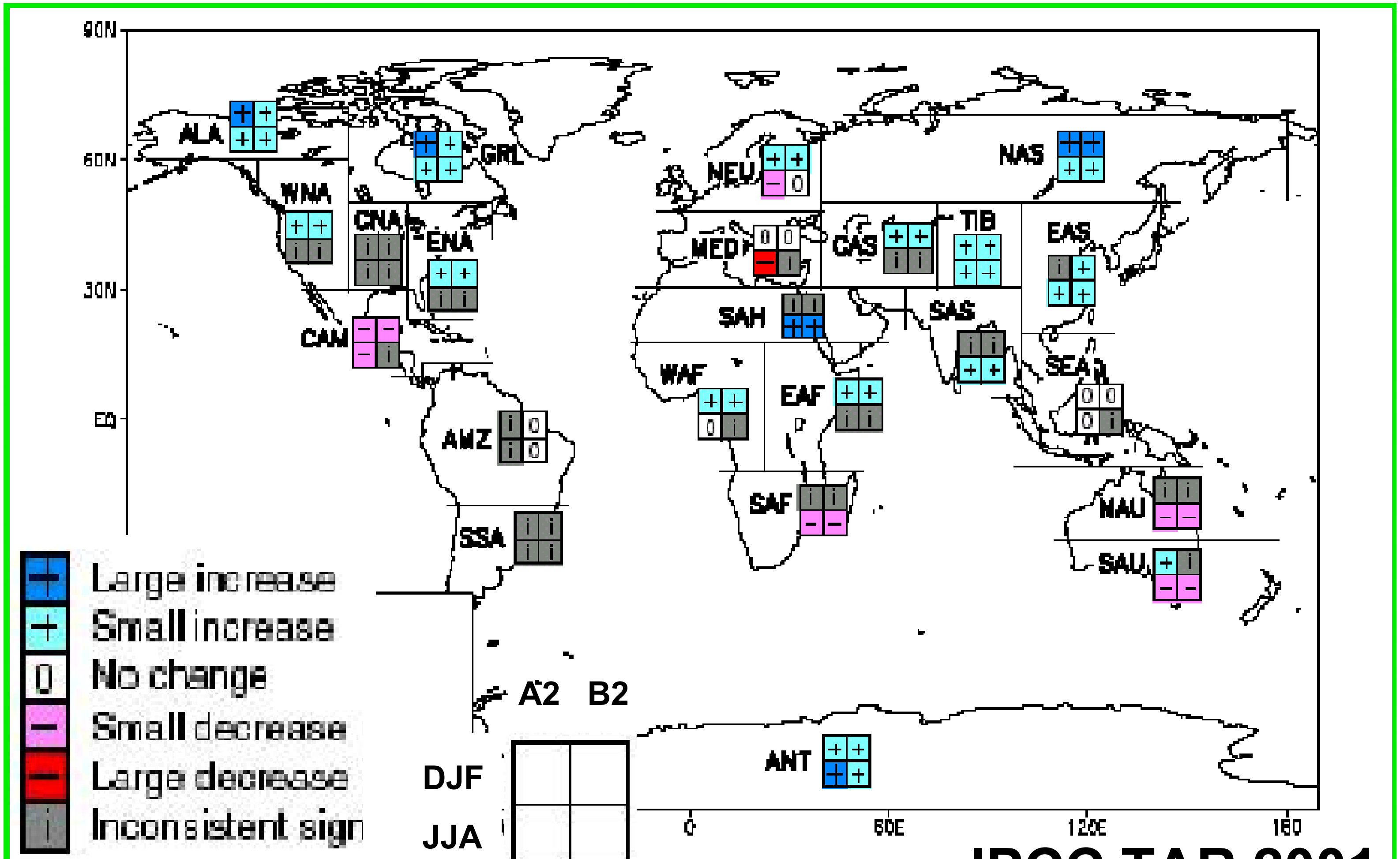
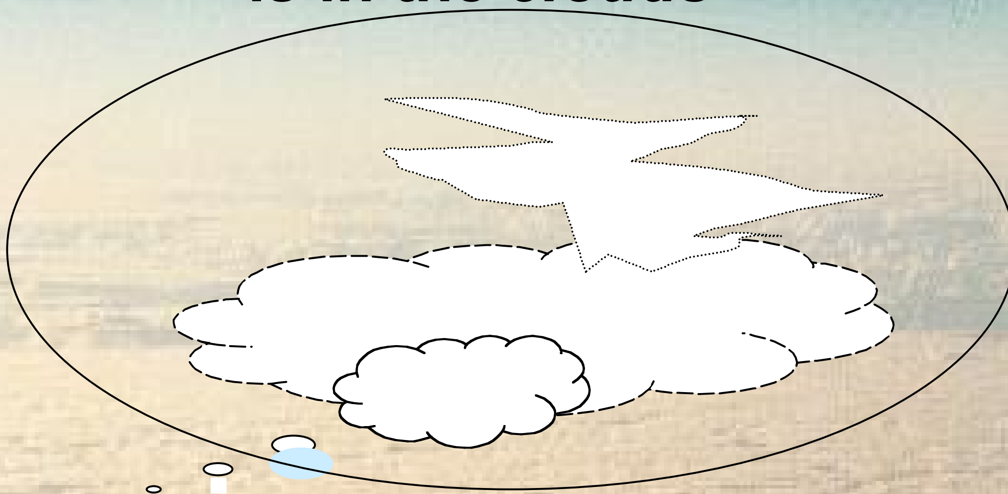
The Challenge : *In*consistency of Model Projections of Regional Precipitation Changes

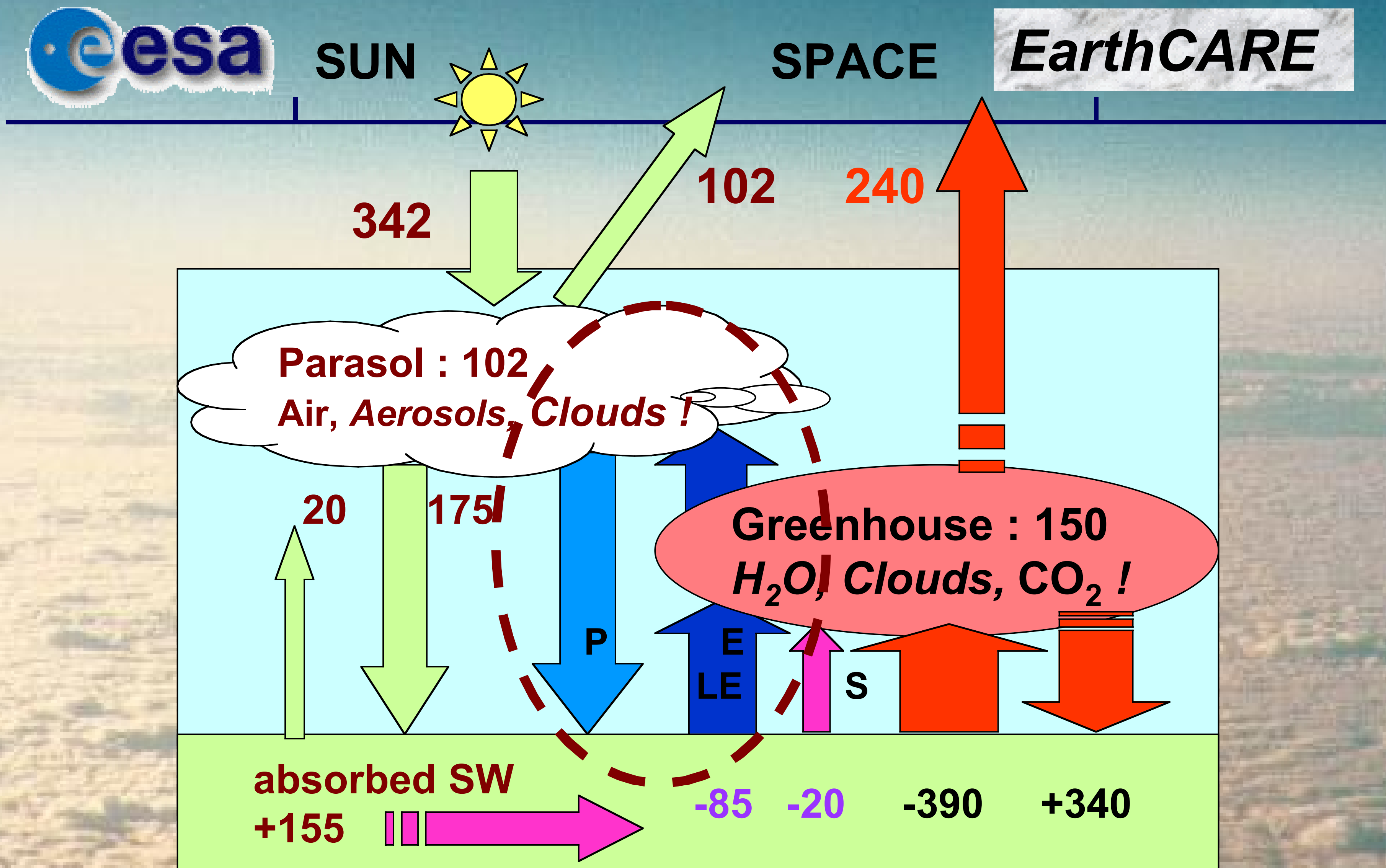


IPCC TAR 2001

The problem (or a *major* problem) is in the *clouds*



1) The site of condensation, thus a site of control of atmospheric water vapor, the principal greenhouse gas
2) Major actors in the SW component of the Earth radiation budget, significant actors in the LW
3) The source of precipitation, essential for land life



The *Linked* Global Water and Energy Cycles

The challenge
Required observations

Clouds

- Geometry (top, base, multiple layers, fractional cover/overlap)
- Vertical profiles of ice/liquid water content and ice particle size
- Super-cooled cloud layers
- Small scale (1km) fluctuations in cloud properties.
- Light precipitation
- Vertical motions

Aerosol

- Height and optical depth of aerosol layers, aerosol size and type

Radiation

- Short-wave (SW) and long-wave (LW) radiances at TOA
- Spectrally resolved top of the atmosphere LW radiances
- Water vapour and temperature profiles

The mission
Approach

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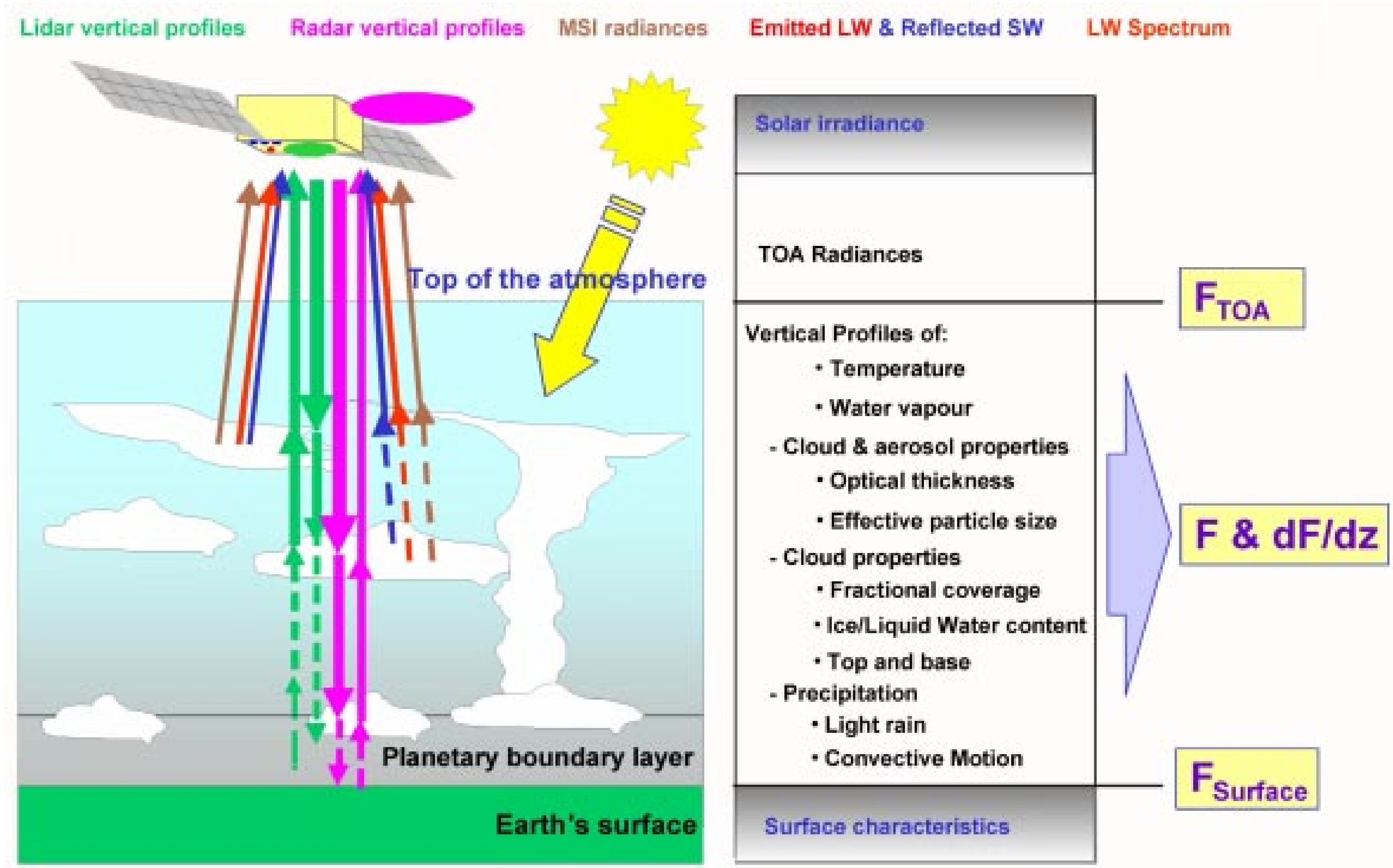


Requirement is to measure the vertical profiles with an accuracy such that the instantaneous TOA flux is derived within ±10 W m^{-2}

Providing VERTICAL PROFILES

- **Lidar (ATLID)** α vertical profiles of aerosols and clouds, but is attenuated by thick clouds.
- **Radar (CPR)** α cloud top and cloud base and ice content inside all ice clouds (negligible attenuation).
- **Reliable retrievals** using both active instruments are only possible with **co-location** of (quasi-) simultaneous samples.
- The **lidar** and **radar together,** viewing the **same cloud column,** yield cloud particle size and water content profiles.

- The **Multi-Spectral Imager (MSI)** provides high resolution data from which improved ISCCP-style procedures, supply **the horizontal context** of the vertical column observations.

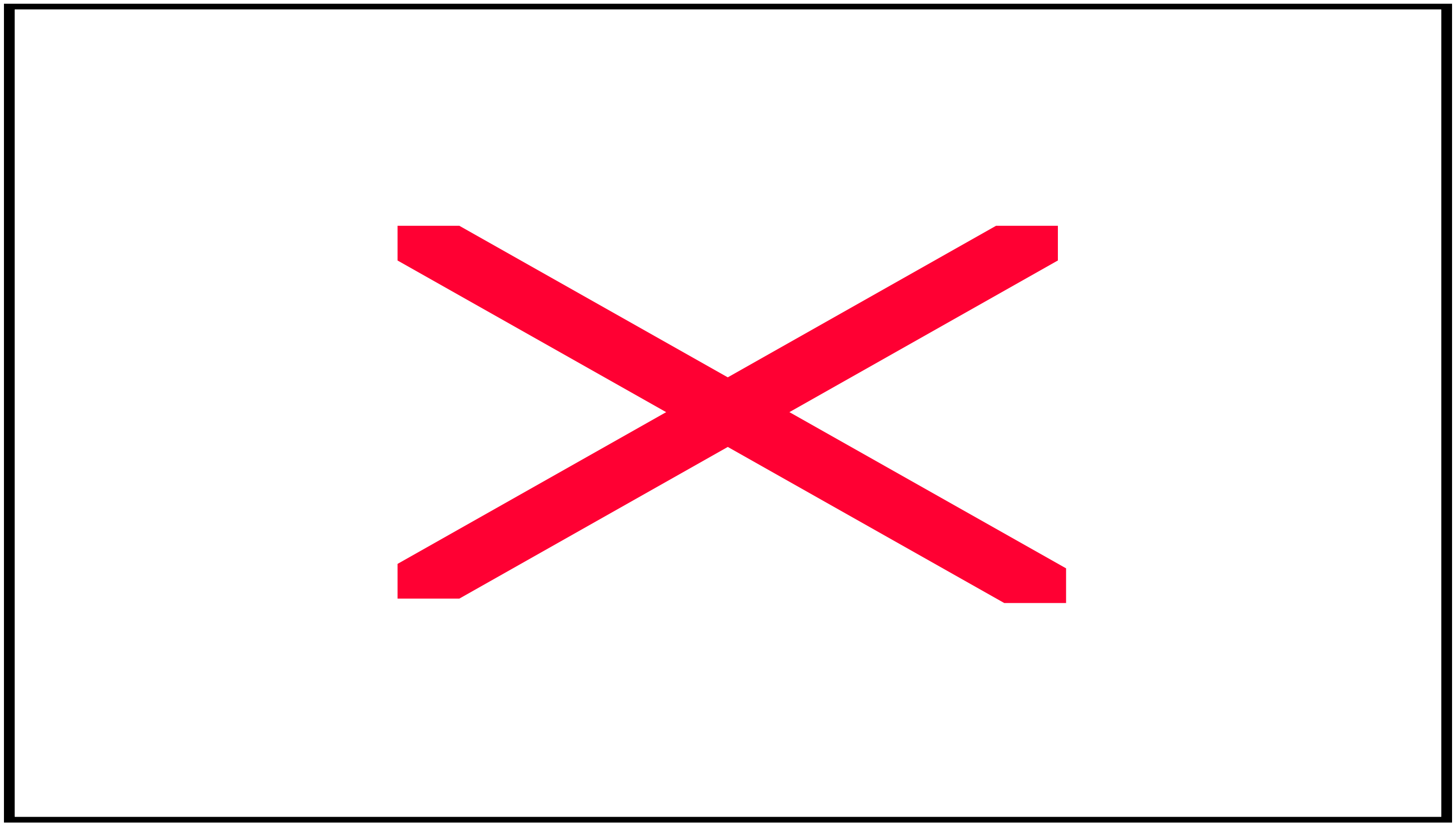
- The **Broad Band Radiometer (BBR)** measures the SW and LW radiances at the Top-of-the-Atmosphere, providing an **essential check** on uncertain radiation calculations for the non-plane-parallel cloud fields.

- The **Fourier Transform Spectrometer (FTS)** provides spectrally resolved TOA LW fluxes and **temperature and water vapour profiles** above clouds (and in clear air).

EarthCARE will provide quantitative information on clouds and aerosols, so that the upward and downward radiative fluxes can be computed at all levels of the atmosphere. As a consequence it will also modify our perception of existing datasets.

The mission
Geophysical requirements

Requirement: to measure the vertical profiles with an accuracy such that the instantaneous TOA flux is derived within ±10 W m^{-2}



Requirements:

Detect radiatively significant clouds/aerosols (extinction coeff (α) >0.05 km^{-1})

α **backscatter (_) sensitivity of 8 10^{-7} m^{-1} sr^{-1} (10 km horizontal integration)**

Derive cloud and aerosol optical depth and identify particle type and habit

α **dual wavelength or High-Spectral Resolution Laser (HSRL)**

α **measure depolarisation**

Conventional lidar problems:

attenuation correction , (unknown) lidar ratio, multiple-scattering

HSR Lidar addresses these issues by:

using molecular backscatter as a reference and a small footprint

α **True α and _ : their ratio gives ice size/habit and aerosol size/type**

Note: LIDAR Backscatter (_) varies as _N D^2 but subject to attenuation

_(observed) = M _(true) exp (-2 ∫ α(r) dr)

multiple scattering↑ ↑ (attenuation along path length r)

Lidar Ratio = α/ _, varies with particle size and type

Requirements:

Detect radiatively significant ice clouds [extinction (α) >0.05 km^{-1}]

- **α radar sensitivity of -38 dBZ (10 km horizontal integration)**
- **α 500m vertical range resolution**

Identify precipitation and vertical motion

- **α Doppler measurements**

Accuracy 1 m s^{-1}: information on convective motion

- better accuracy will supply information on ice sedimentation in cirrus and drizzle

Note: Radar reflectivity, Z = _ N(D) D^6 dD,

N is the droplet concentration and D droplet size.

Z in mm^6 m^{-3}, usually expressed in dBZ (log units with respect to one mm water drop in a m^3)

Radiatively significant clouds

Ice

- ➔ -38 dBZ will detect 99% of these ice clouds (ARM Great Plains dataset)
- ➔ Factor of 2 (+100% / -50%) error in IWC from reflectivity (Z) alone
- ➔ For IWC and particle size, error of ~30% α use lidar-radar synergy
- ➔ Lidar(~D^2) – radar (~D^6) backscatter ratio provides size information

Water

- ➔ Smaller droplets α radar reflectivity very often below –38 dBZ
- ➔ LWC cannot be derived from Z alone α use lidar and imager
- ➔ Supercooled layers signature α high lidar signal, no radar signal

➔ Radar-lidar footprint co-location necessary

Fourier Transform Spectrometer Requirements:

Water vapour & temperature profiles consistent with instantaneous ±10 Wm^{-2}

- 30% accuracy for water vapour and 1.5 K for temperature
- on 2 km vertical resolution

Spectral resolved long-wave (LW) TOA radiances (to be used with BBR)

- 5.7 to 25 µm, unapodised resolution of 0.5 cm^{-1}
- 10 km footprint

Broad Band Radiometer Requirements:

Estimation of instantaneous TOA fluxes better than 10 W m^{-2} to validate or constrain the measurements from the other instruments

- 3 views (nadir, fore and aft) with a relatively small footprint for this type of measurements (10 km)

Measurement of TOA radiances consistent with 10 W m^{-2} (instantaneous)

- radiance measurement better than 3 W m^{-2} sr^{-1} for each of the views

Multi-Spectral Imager Requirements:

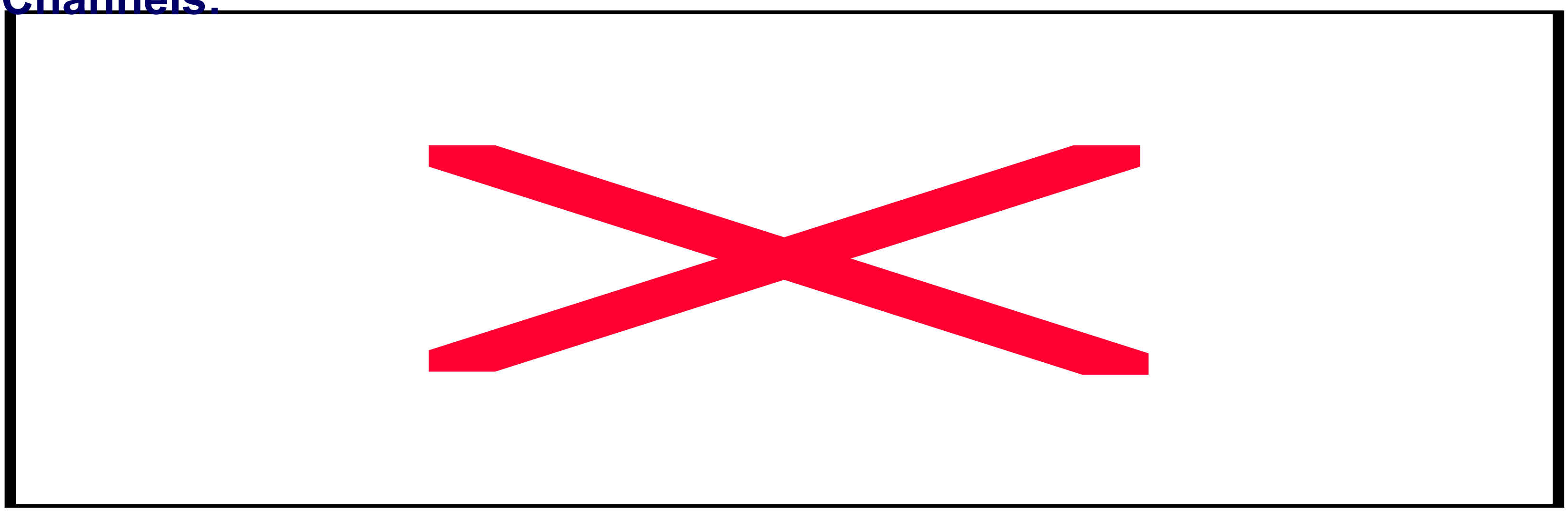
Supply the context of the narrow swath measurements

- α swath large enough to understand the context (150 km) and good spatial resolution (500 m)

Characteristics of topmost clouds

- α 7 channels, no Sun-glint and good signal-to-noise ratio

Channels:



W: water clouds, Ci: Cirrus

Synergy
Footprints and sampling

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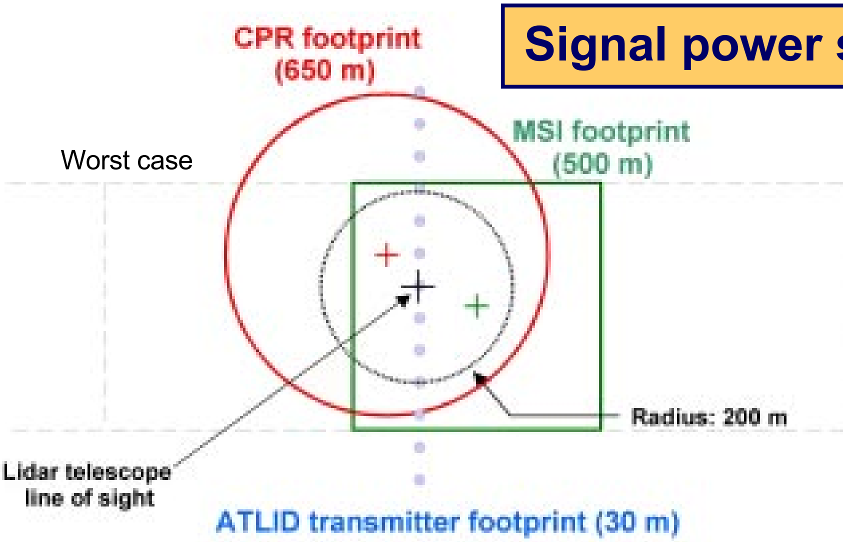


Signal power spectrum ∝ d^2 even for a distance of 30 m

Footprints

Lidar: row of 30 m (70 m separation)

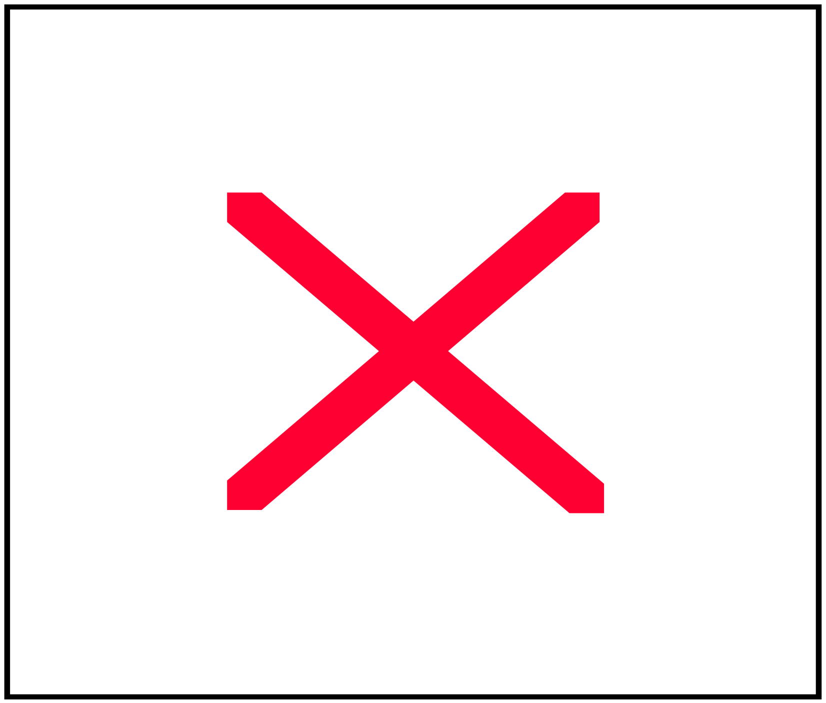
Radar: 650 m

MSI: 500 m (150 km swath)

FTS & BBR: 10 km

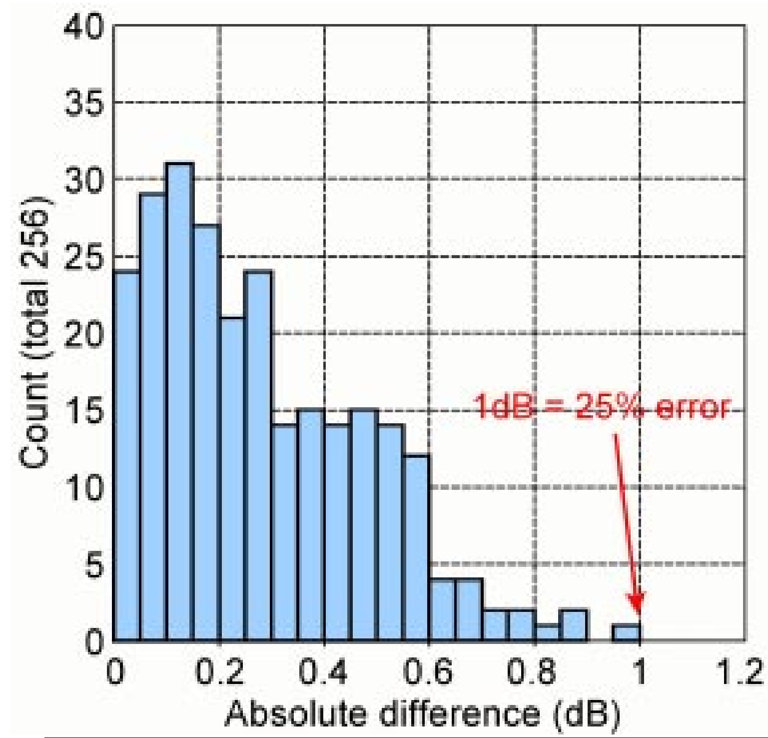
"Flying" the instruments over clouds with extreme variability (d^2 spectrum)

One realisation of a cloud field



- 500 m scale α small variability
- 3 km spot separation α very large 70% error

CASE 1 – CASE 2



Footprints	Lidar	Radar
CASE 1	650 m	650 m
CASE 2	30 m (row of 10)	650 m

Conclusions
Delivered products

Clouds

- Geometry (top, base, multiple layers, fractional cover/overlap)
- Vertical profiles of ice/liquid water content and ice particle size
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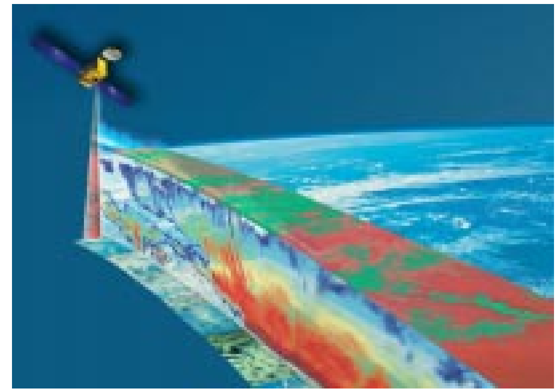
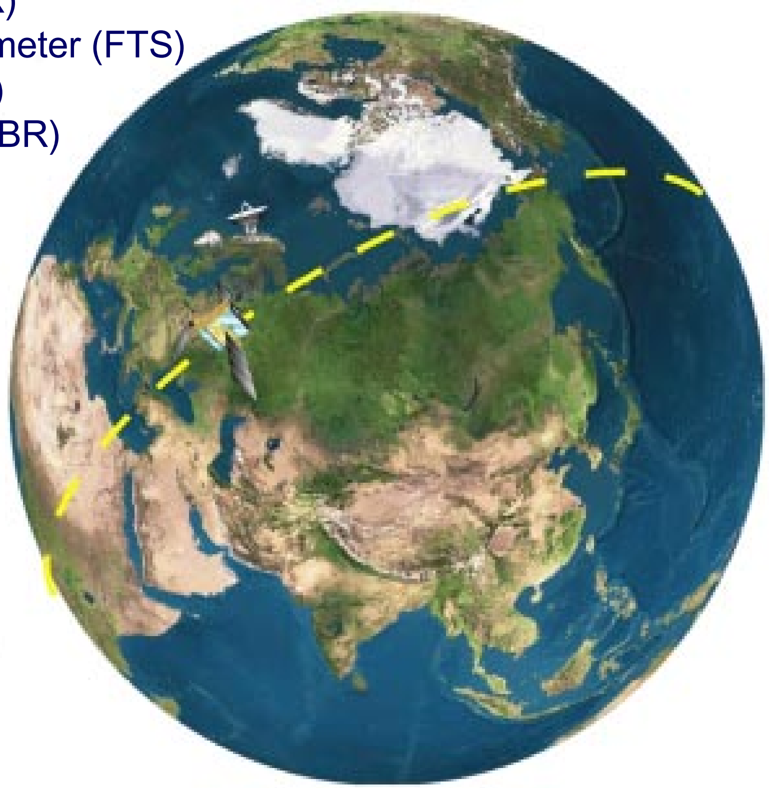
System Concept
Mission Summary



SPACE SEGMENT

Payload
- Backscatter Lidar (ATLID)
- Cloud Profiling Radar (CPR)
- Fourier Transform Spectrometer (FTS)
- Multi-Spectral Imager (MSI)
- Broad Band Radiometer (BBR)

Platform



MISSION PARAMETRES

- Sun synchronous orbit
- Altitude 416 km … 432 km
- Local time 10:30 DN
- Mission life 2 years (+1)
- Launch date 2008 - 2010

LAUNCH VEHICLE

- H2A (Dual) ***Baseline***
- Soyuz (Dual)
- Local time 10:30 DN
- PSLV (Single)

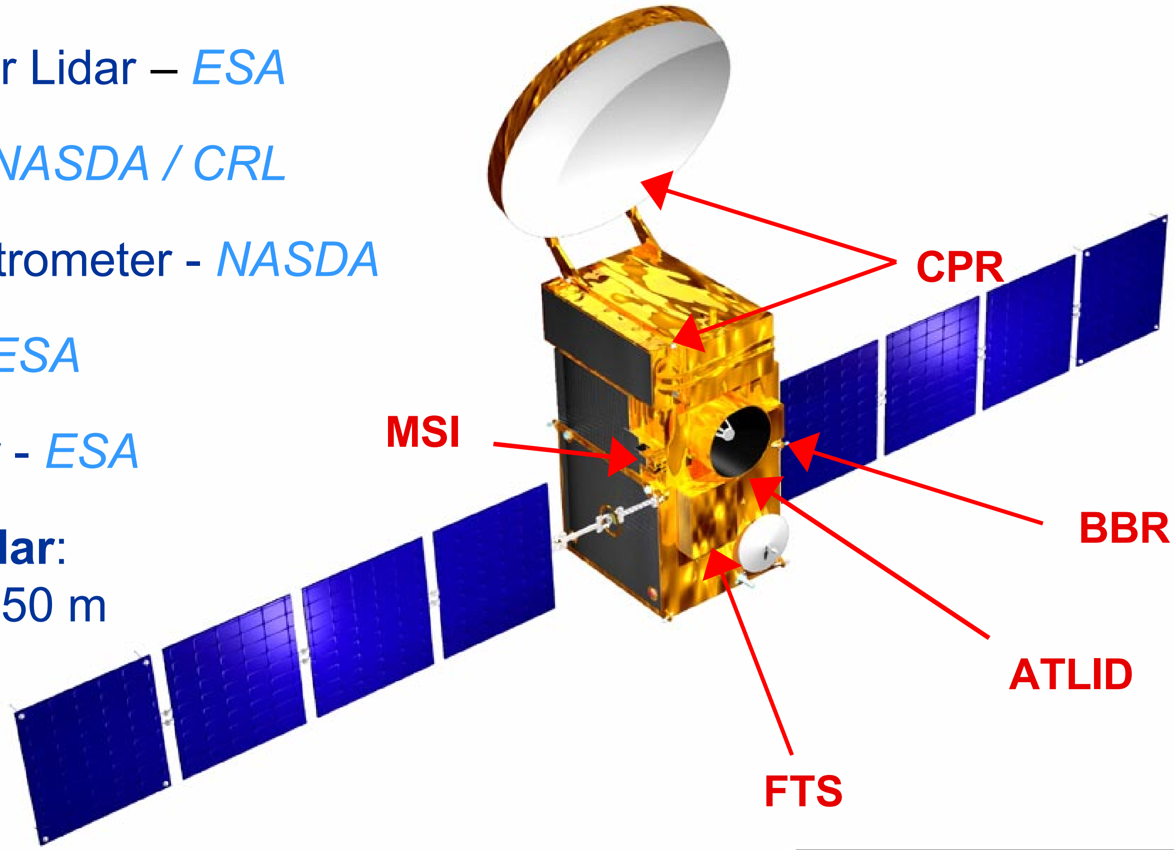
GROUND SEGMENT

- Command and data acquisition (eg Kiruna)
- Mission and satellite control and planning
- Processing, distribution and archiving

Five instruments accommodated on a single platform

- Atmospheric Backscatter Lidar – *ESA*
- Cloud Profiling Radar - *NASDA / CRL*
- Fourier Transform Spectrometer - *NASDA*
- Multi-Spectral Imager - *ESA*
- Broad Band Radiometer - *ESA*

Co-registration with Lidar:
- CPR and MSI: 200 … 350 m
- FTS and BBR: 1 km



- Platform - *ESA*
- Launcher - *NASDA*
- Ground Segment - *ESA / NASDA*

System Concept
Orbit and Lifetime

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- Sun-synchronous orbit
- Two orbit options: 416 km with 2 day repeat and 432 km with 7 day repeat
- Node crossing at 10h30.
- Dual launch with GCOM-B1 by H-IIA
  - α Injection into an intermediate elliptic orbit (apogee = GCOM-B1 altitude perigee = EarthCARE altitude)
  - α Orbit correction individually by the two satellites
- Lifetime 2 plus 1 year

NASDA CRL

Multi-Spectral Imager (MSI)
Requirements and Performance

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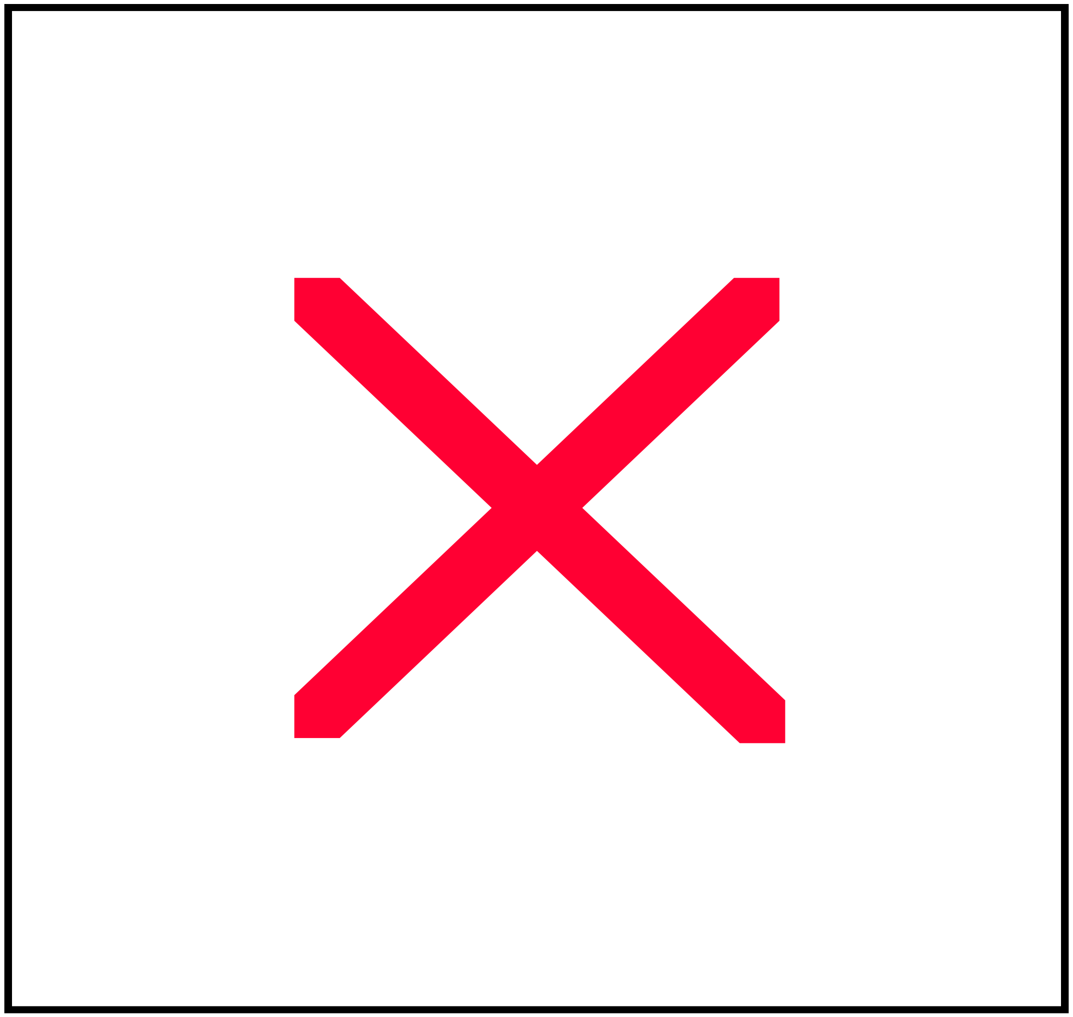
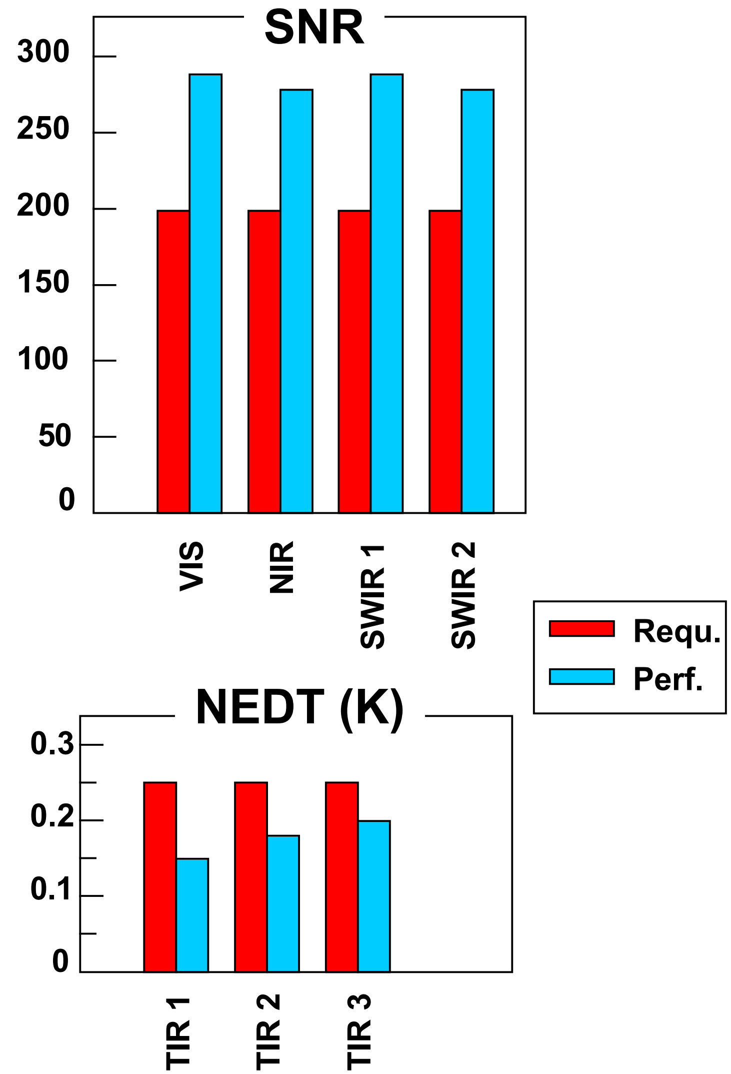
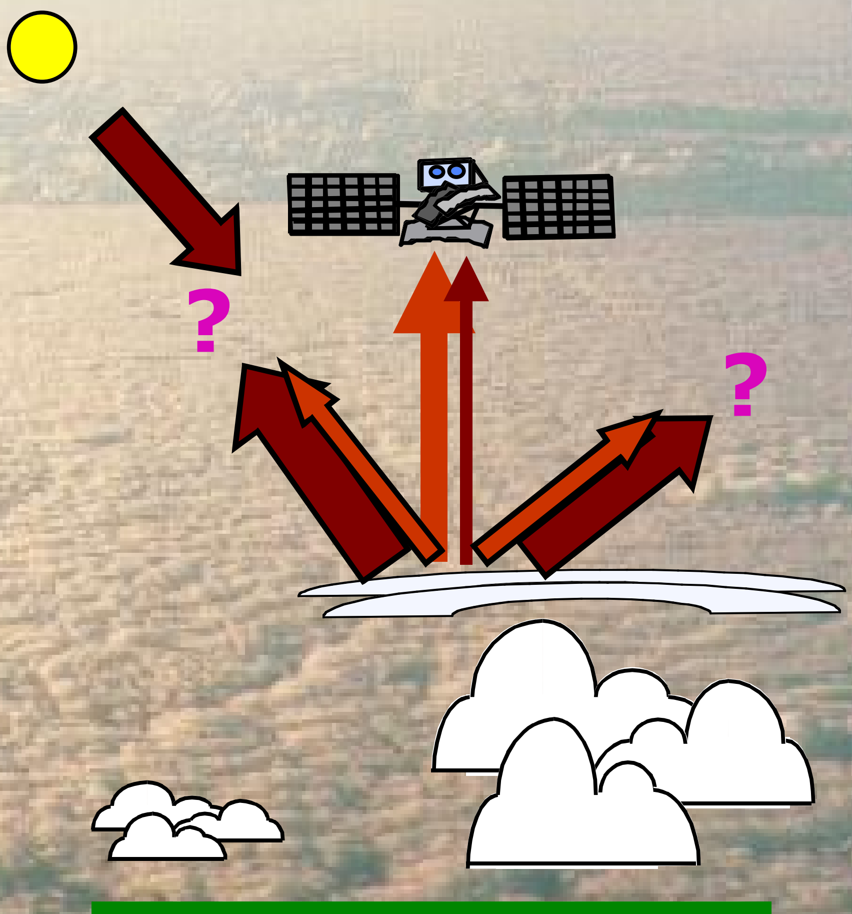




Instantaneous Radiative Flux Products Needed Along Track

Problem : For the volumes sounded at a time *t*, only *radiances*, *not* fluxes, can be observed.

Angular distribution models used to convert TOA radiances into flux estimates are *unreliable for instantaneous reflected SW*.



3-view BBR

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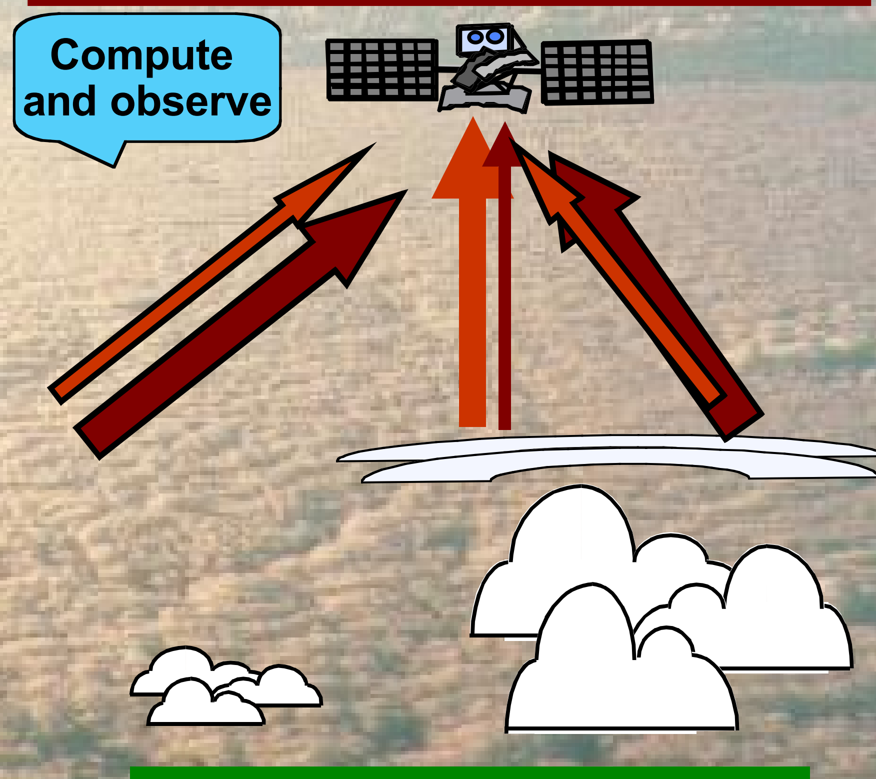
One Solution : As in ISCCP, calculate SW and LW fluxes from the *physical properties,* retrieved from more complete synergetic *EarthCARE* data on the *in-cloud* properties.

Compare computed emergent SW *radiances* and LW *radiances* and spectrum with *EarthCARE observed SW and LW radiances (BBR) and LW spectrum (FTS)*

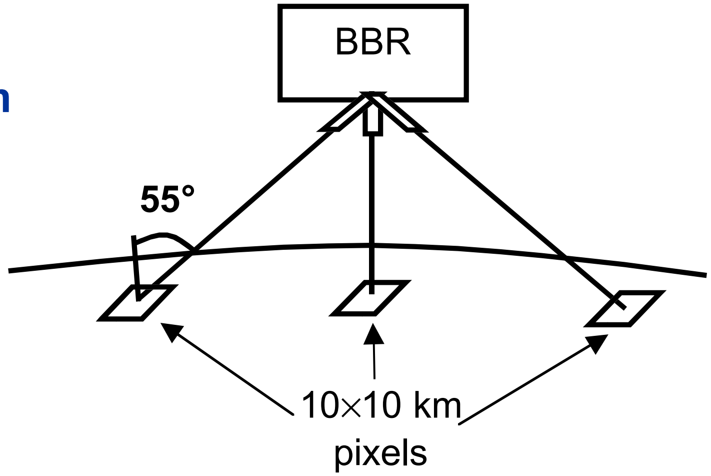
EarthCARE BBR

Get 3 views along track for better observational TOA flux estimates



Broad Band Radiometer (BBR)
Requirements

- Along track sampling: 3 telescopes
- Telescope zenith angle: θ = 0º, ± 55º
- Pixel size : - 10 km x 10 km for all three cameras
  - 0.1 pixel registration
- Two spectral channels: - SW: 0.2 - 4.0 µm
  - LW: 4.0 - 50 µm
- Calibration:
  - Sun calibration via diffuser
  - Deep space calibration
  - Black body calibration



Broad Band Radiometer (BBR)
Design Concept and Performance

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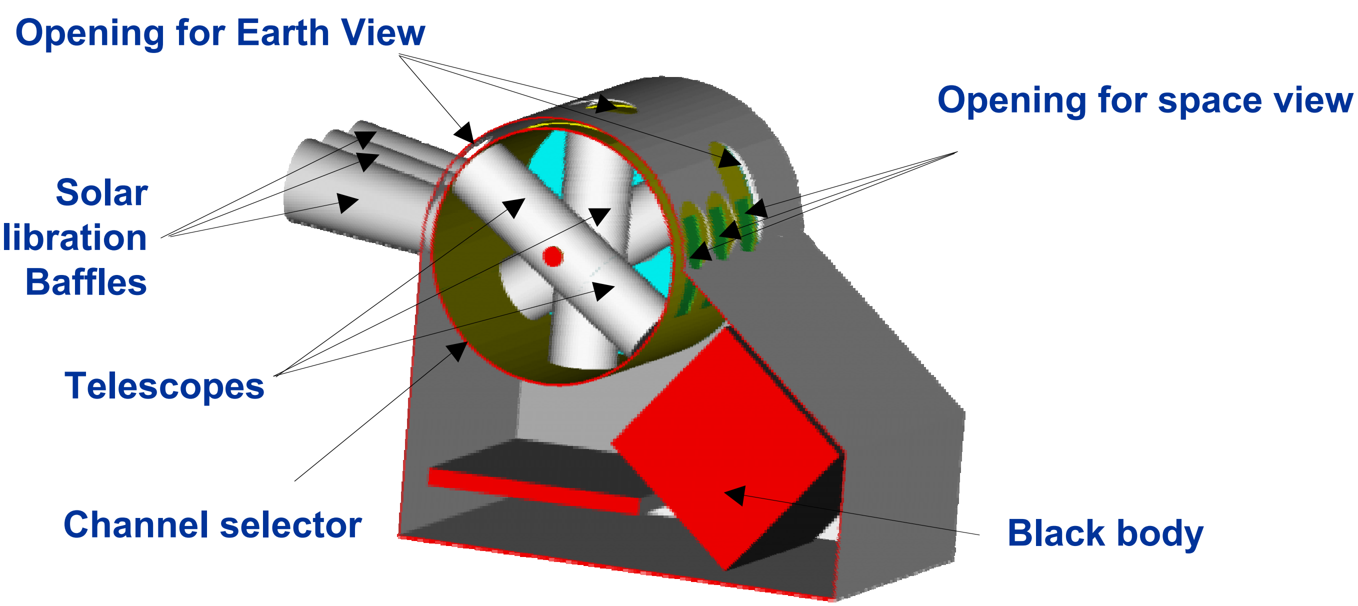
Flux accuracy (SW Channel)	1σ value W.m^{-2}
Instrument	7.20
Unfiltering	2.60
Flux retrieval	4.00
Quadratic sum	8.7

Mass	15 kg
Power	20 W
Data rate	20 kbit/s



Ground Segment

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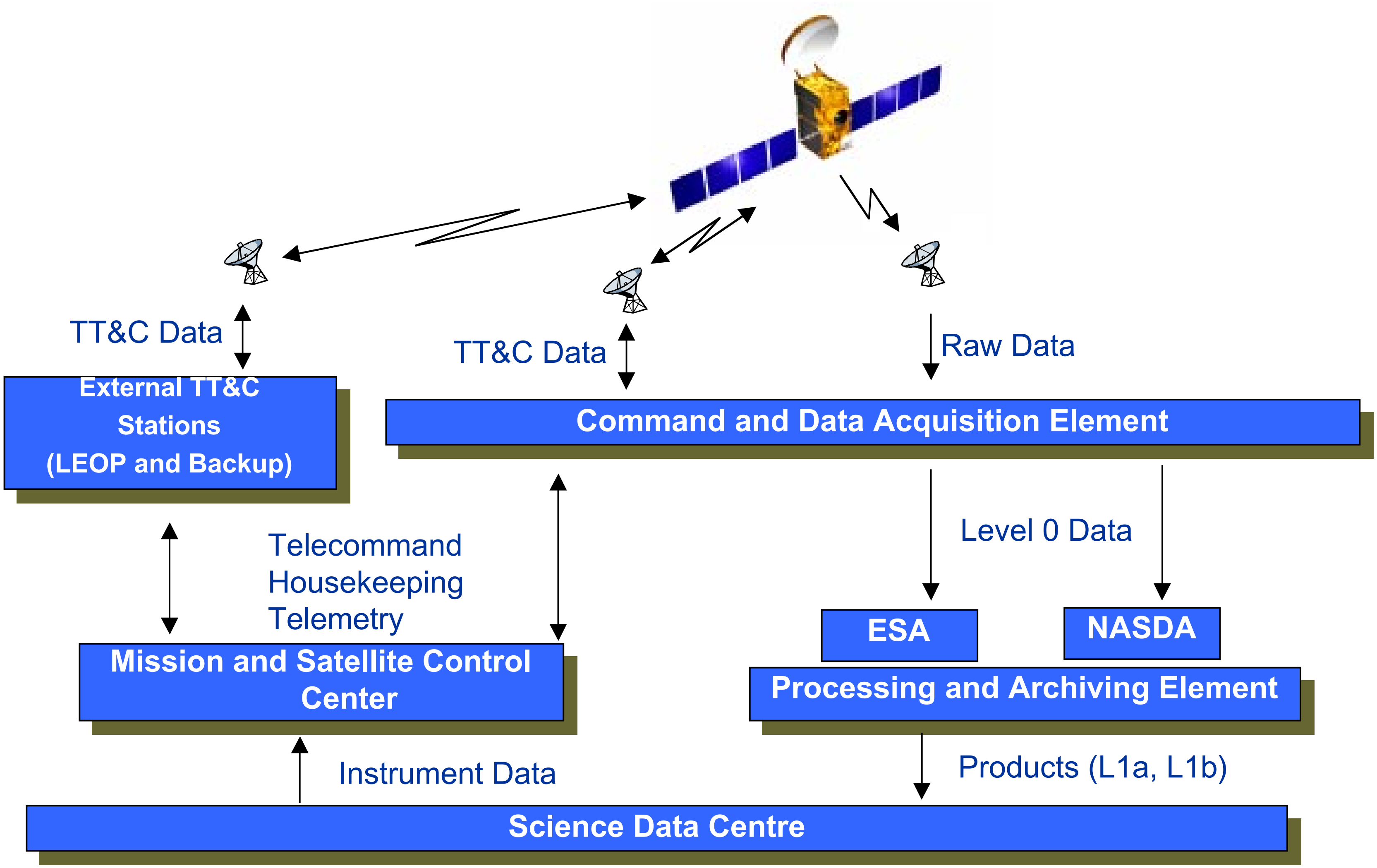

Programmatic Aspects

- **ESA / NASDA / CRL cooperation**
- **Low development risk**
- **Strong heritage for all components**

Lidar	**ATLID/ERM, Aeolus**
CPR	**CloudSat/ERM (in particular EIK)**
FTS	**SOFIS/IMG**
MSI	**Detectors currently under development**
BBR	**ScaRaB**

Conclusions
Final remarks

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- **Uncertainties** in predicting global warming **must be reduced**
- **Biggest uncertainty** is associated with **clouds, cloud-aerosol interaction and cloud feedback**
- **EarthCARE** provides, **in a radiatively consistent manner**, vertical profiles of clouds and aerosols to evaluate numerical models (climate and NWP) and to validate parameterisations using **in synergy**:
  - **Radar:** very sensitive + Doppler
  - **Lidar:** high spectral resolution α **TRUE** backscatter and optical depth of clouds and aerosols.
  - **FTS, MSI and BBR** α flux profiles to 10 W/m^2 TOA
- **EarthCARE** will provide quantitative information on clouds and aerosols, so that the **upward and downward radiative fluxes** can be computed **at all levels** of the atmosphere, solving the biggest current uncertainty in climate and NWP modelling

Synergy

- **Ice clouds** — Lidar-Radar-MSI
  Profiles of IWC, particle size & optical depth
- **Water clouds** — Lidar-Radar-MSI
  Profiles of LWC, particle size & optical depth
- **Aerosols** — Lidar-MSI
  Optical depth, size & type
- **Aerosol-cloud interaction**
  Lidar-Radar-MSI — all 3 above
- **TOA fluxes** — BBR-FTS-MSI

Single instrument

- **Precipitation** — Radar
- **WV & T profiles** — FTS
- **Data from other sources**

Synergy → **Radiative flux profiles**

Artist's impression

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